Validity and Reliability of Skinfold Measurement in Assessing Body Density and Body Fatness of Chinese Children in Hong Kong: Using Air Displacement Plethysmography as a Criterion Measure

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ABSTRACT

The prevalence of childhood obesity in Hong Kong has increased close to 70% in the past 13 years. For tracking the childhood obesity level effectively, there is an urgent need to evaluate the obesity level of children in Hong Kong using objective and practical measurement. Using Air Displacement Plethysmography (ADP) as a criterion, we evaluated the validity and reliability of skinfold (SKF) measurement in predicting body density and percent body fat of Chinese children in Hong Kong. A heterogeneous sample of healthy voluntary Chinese children (142 boys and 88 girls) with a wide age range (9-19 years) and body composition was recruited through stratified purposeful sampling. The reliability of skinfold and ADP measurements were very high ($r \geq .988$). Repeated *t*-test showed no significant difference between %fat measured by ADP (%fat_{ADP}) and that measured by dual X-ray absorptiometry in a sub-sample (N = 41), and significant difference was found between percent fat estimated by the Slaughter equations (%$fat_{Slaughter}$) and %fat_{ADP}. The Slaughter equations slightly underestimate %fat of Hong Kong children, 1.52% for boys and 1.84% for girls. Despite the high R squares (.81 for boys and .64 for girls), the slope of the regression line for boys was significantly different from the line of identity. Subsequent stepwise regression analyses found three alternative skinfold prediction models for estimating percent body fat of Chinese children in Hong Kong, which

including waist circumference, height and children's age. The most accurate model for boys was %fat = 22.091 -0.147 (height) + 0.760 ($\sum$3SKF) - 0.003 $(\sum 3SKF)^2$ (R square = .88, SEE = 3.70), and that for girls was %fat = 17.539 + 0.303 ($\sum$2SKF) + 0.516 (height) -0.175 (waist circumference) (R square = .71, SEE = 3.38). The third model for boys and girls was the convenient model, as only triceps skinfold and age is required for the estimation. The equation for boys was %fat = 14.405 + 1.479 (triceps) - 0.856 (age) (R square = .81, SEE = 4.67), and the equation for girls was %fat = 13.936 + 1.170 (triceps) - 0.502 (age) (R square = .63, SEE = 3.77). The accuracy of these models is comparable to the Slaughter equations, but the estimated %fat by these new models were less deviated from $\%fat_{ADP}$ than that estimated by the Slaughter equations.

摘要

香港兒童的肥胖問題在最近13年總共增加了近70%。我們有需要以客觀及實用的量度方法從而評估及追蹤香港兒童肥胖的情況及趨勢。以排空氣法(ADP)為標準，我們分析以皮摺厚度量度來測量的身體密度及脂肪比例(%fat)的信度和效度。

本研究以有目的的分層抽樣方法招募了230位由不同身體質量指數及年齡組成的中國藉兒童(142名男童及88名女童，9至19歲)。結果發現皮摺厚度和ADP的信度均非常高($r \geq .988$)。重複性t測試(N = 41)顯示以ADP量度的%fat(%fat_{ADP})與DXA所得出的結果沒有顯著差別，而%fat_{ADP}與以Slaughter方程式推算的%fat(%$fat_{Slaughter}$)所得出的結果有著顯著差別。Slaughter方程式低估了香港男童的1.52%fat及香港女童1.84%fat。雖然有著高R^2 (男童：.81，女童：.64)，但男童的回歸方程線的斜度顯著地有別於恆等線。隨後，逐步回歸分析發現三個結合腰圍、身高及年齡從而替代的皮摺厚度推算模型。供男童使用的最準確模型為：%fat = 22.091 -0.147 (height) + 0.760 ($\sum$3SKF) - 0.003 ($\sum$3SKF)^2 (R^2 = .88, SEE = 3.70)，供女童使用的最準確模型為：%fat = 17.539 + 0.303 ($\sum$2SKF) + 0.516 (height) -0.175 (waist circumference) (R^2 = .71, SEE = 3.38)。第三個模型為最方便模型，因只需要代入三頭肌皮摺厚度及年齡以供計算。供男童使用的方程式為：%fat = 14.405 + 1.479 (triceps) - 0.856 (age) (R^2 = .81, SEE = 4.67)，而供女童使用的方程式為：%fat = 13.936 + 1.170 (triceps) - 0.502 (age) (R^2 = .63, SEE = 3.77)。這三個

模型的準確度比得上Slaughter方程式，但新模型推算的%fat比%$fat_{Slaughter}$的偏差較少。

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INTRODUCTION

Childhood obesity is a worldwide growing epidemic. A high prevalence and increasing rates of childhood obesity are reported globally , including the United States (Ogden, Carroll, Curtin, McDowell, Tabak, & Flegal, 2006), England (Stamatakis, 2003), and mainland China (Ji & Sun, 2004). An estimated 22 million children under five years old are overweight worldwide. Obesity is one of the major contributors to the global burden of chronic disease and disability, including type 2 diabetes, cardiovascular disease, hypertension and stroke, and certain types of cancer. The health consequences range from increased risk of premature death, to serious chronic conditions that reduce the overall quality of life.

The prevalence of childhood obesity in Hong Kong has increased closed to 70% in the past 13 years (Yeung & Hui, 2007). However, question has been raised about the definition of childhood obesity using the weight/height ratio which has been adopted since 1993, as the local standard uses weight-for-height as the criteria to define childhood obesity, which is considered a screening tool of body shape rather than an accurate measurement of body fatness in Hong Kong children (Yeung & Hui, 2007). Scientists have commented that weight/height ratio is only a crude index of body composition and cannot accurately reflect the body fatness of individual. Hence, for tracking the childhood obesity level effectively, there is an urgent need to evaluate the obesity level of children in Hong Kong using objective and practical measurement.

There are various ways of measuring human body composition. Laboratory measurement, while precise, involves sophisticated equipments and complex procedures and trained technicians. Field methods, though less accurate compared with laboratory methods, are much simpler and inexpensive, and can be carried out with large group of people in community or school settings. However, not all of them are appropriate to be carried out on children. An accurate, reliable while convenient way of assessing pediatric body composition is essential for monitoring childhood obesity in Hong Kong and over the world. Among various laboratory methods, the ADP method is a more desirable body composition method for young children because it is safe and easy to use. In terms of accuracy, a number of studies indicate that the results of body fat measurement using the ADP method is comparable to those obtained by underwater weighing and four-compartment model (Dewit, Fullera, Fewtrell, Elia, & Wells, 2000; Fields & Goran, 2000; Fields, Goran, & McCrory, 2002; Going, 2005).

Scientists suggest the use of skinfold method, the measurement of subcutaneous fat, in field setting as an alternative of laboratory method. Currently it is the most widely adopted field method of body fat measurement in children (Heyward, 2006; Heyward & Stolarczyk, 1996). Since the instruments are portable, inexpensive and non-invasive, skinfold method can be readily applied in clinics, laboratories and schools. It also has high correlation with percent body fat (Billisari & Roche, 2005).

At the moment, the Slaughter equations (Slaughter et al., 1988) are the most widely used skinfold equations for pediatric measurement of body fatness. These equations may be used to assess the body composition of African American and Caucasian children aged 8 to 17 years old, but may not be not valid to use on Hong Kong children. It is because these prediction equations are age and race specific, and validation has to be done before applying these equations on Hong Kong children (Hui, Chan, Wong, Wong, & Lau, 2001). Nevertheless, skinfold measurement of Hong Kong school children has been collected for many years. Practitioners in Hong Kong simply adopt the sum of skinfolds to get a rough idea of body fatness, or erroneously applying the Slaughter equations to get an estimation of body fatness.

Nonetheless, through appropriate validation of these equations with criterion measure of body composition, these skinfold equations will be applicable to Hong Kong children. The skinfold method will then become an appropriate method for measuring pediatric body composition, so that it will be possible to monitor the prevalence of childhood obesity accurately and efficiently in Hong Kong.

Purpose and Significance

The purpose of this study was to examine the validity and reliability of skinfold measurement in predicting body density and percent body fat (%fat) of Chinese children in Hong Kong aged 9 to 19 years old, using Air Displacement Plethysmography (ADP) as criterion. It is important to develop valid skinfold equations so that pediatric body composition and childhood obesity can be evaluated accurately. With more accurate evaluation, effectiveness of health promotion strategies in Hong Kong can be evaluated.

Hypotheses

It is hypothesized that: 1) skinfold measurements were effective predictors of body density and %fat of Chinese children in Hong Kong aged 9 to 19 years old; 2) there was no difference between %fat estimated from Slaughter equations and criterion %fat measured from ADP; 3) there was no difference between %fat estimated from skinfold equations developed from this study and criterion %fat measured from ADP; and 4) the reliability of skinfold measurements, and the reliability of body volume, body density and %fat measured from ADP in children were high.

Delimitation

1. Only Chinese children aged 9-19 years old were recruited in the present study.
2. Two-component body composition model were adopted.

Limitation

1. The results of the study were only generalized to Chinese children in Hong Kong.
2. ADP was used as the criterion measurement of children body composition.
3. It was assumed that participants would follow the guidelines on diet and exercise before measurement honestly.
4. It was assumed that participants would be able to follow all testing procedures during measurement.
5. The effect of season and time of measurement on the hydration level and body

composition of children was unknown.

Operational Definitions

Body composition

A component of physical fitness; absolute and relative amounts of muscle, bone, and fat tissues composing body mass. In this study, body composition is defined as the relative proportion of fat tissues in the body measuring by ADP.

Body density

The overall density of the fat, water, mineral, and protein components of the human body; total body mass expressed relative to total body volume. In this study, body density is defined as the body mass expressed relative to the total volume, which is measured by ADP.

Children

Young human being below the age of full physical maturity. In this study, children were defined as individuals aged between 9-19 years.

Triceps skinfold

Thickness of subcutaneous adipose tissue near the triceps; vertical fold is taken on the posterior midline of the upper arm, halfway between the acromion and olecranon process, with arm held freely to the side of the body.

Subscapular skinfold

Thickness of subcutaneous adipose tissue under the scapula; diagonal fold is taken at one to two cm below the inferior angle of the scapula.

Suprailiac skinfold

Thickness of subcutaneous adipose tissue above the iliac crest; diagonal fold is taken in line with the natural angle of the iliac crest taken in the anterior axilliary line immediately superior to the iliac crest.

Abdominal skinfold

Thickness of subcutaneous adipose tissue at the abdomen; vertical fold is taken at two cm to the right side of the umbilicus.

Thigh skinfold

Thickness of subcutaneous adipose tissue at the thigh; vertical fold is taken on the anterior midline of the thigh, midway between the proximal border of patella and the inguinal crease.

Calf skinfold

Thickness of subcutaneous adipose tissue at the calf; vertical fold is taken at the maximum circumference of the calf on the midline of its medial border.

Body mass index

Body mass index (BMI) is defined as the individual's body weight in kilograms divided by the square of their height in meters.

Body height

Body height refers to the stature of the individual, which will be measured by a calibrated stadiometer when subjects wear minimal clothing with bare feet.

Body weight

Body weight refers to the mass of the individual, which will be measured by a calibrated electronic digital scale when subjects wear minimal clothing with bare feet.

Waist circumference

Waist circumference is measured at the narrowest part of the torso, above the umbilicus and below the xiphoid process using a Gulick Tape.

REVIEW OF LITERATURE

The aim of this chapter is to review different aspects which related to childhood obesity. The first section is to describe the prevalence of childhood obesity over the world. In the next section, local trend of childhood obesity is reported. Criteria of defining childhood obesity in Hong Kong are also discussed. Causes of childhood obesity, its health consequence, and local interventions to tackle the problem are then discussed. Theories in measuring body composition in children are reviewed. They include different body composition models, and various body composition measurement methods used in laboratories and field settings. Details of children skinfold thickness equations are discussed in the end of this chapter.

The Epidemic of Childhood Obesity

Obesity is one of the major contributors to the global burden of chronic disease and disability. According to the Surgeon General Report (U.S. Department of Health and Human Services, 1996), an estimated 300,000 deaths per year may be attributable to obesity. It is, however, not only an epidemic for adults. Childhood obesity is a worldwide growing public health problem. A high prevalence and increasing rates of childhood obesity are reported globally. World Health Organization (2004) reported that an estimated 22 millions children under five were overweight worldwide. The problem of childhood obesity is a serious health concern.

Increase in Childhood Obesity Over the World

The problem of childhood obesity was found in different regions in the world. In the United States, children and adolescents overweight is a serious health concern. Data from two National Health and Nutrition Examination Surveys (NHANES) (1976–1980 and 2003–2004) show that the prevalence of overweight is increasing. For children aged two to five years old, prevalence increased from 5.0% to 13.9%; for those aged from six to eleven years old, prevalence increased from 6.5% to 18.8%; and for those aged twelve to nineteen years, prevalence increased from 5.0% to 17.4% (Ogden et al., 2006; Ogden, Flegal, Carroll, & Johnson, 2002).

In England, the International Obesity task Force (IOTF) analysis in 2002 indicates a dramatic acceleration in obesity and overweight in English children from the mid-1980s onwards. In 2002, 21.8% of boys and 27.5% of girls aged from two to fifteen years old were found to be overweight, including 5.5% of boys and 7.2% of girls who were obese, according to the IOTF's international standards (Stamatakis, 2003).

An increasing figure of childhood obesity was also recorded in Asia. In Mainland China, 15.29% of boys and 8.77% of girls were found overweight in several metropolitans, with 9.63% of boys and 4.50% of girls obese, applying “2000 NCHS/CDC Sex-Age BMI Reference”. It was also found that the prevalence of obesity in urban cities is much higher than that in rural cities (Ji & Sun, 2004).

The prevalence of childhood obesity in Hong Kong is similar to that of western countries, as Hong Kong is one of the most westernized cities in China. Studies found that the prevalence of childhood obesity in Hong Kong is increasing drastically in the past decade. In 1993, the Hong Kong Growth Survey, a territory wide cross-sectional survey covering 25000 Chinese children, was carried out by the Faculty of Medicine, the Chinese University of Hong Kong (CUHK) in collaboration with the Department of Health (DH), Hong Kong. It was reported that 13.4% and 10.5% of boys and girls aged 6-18 were obese, in which obesity defined as weight higher than the 120% median weight-for-height using local reference range (Leung, Tse, & Leung, 1996b).

Since then, a few researches were done to track the prevalence of childhood obesity in Hong Kong, using this local definition and standard. In 1997, Guldan and colleagues (1998) found that the rate of obesity was 23% and 10% for boys and girls, respectively. In 2001, the Student Health Service of the Hong Kong Department of Health found that 17% boys and 12% girls were found obese in primary school, and 12% boys and 10% girls for secondary students.

From 2001 to 2006, contracted by the Education and Manpower Bureau (EMB) and the Leisure and Cultural Services Department (LCSD) of Hong Kong, a few cross-sectional surveys were carried out by the Department of Sports Science and Physical Education, CUHK. Height and weight of about 30,000 children were collected and then analyzed. Among these samples, 22.5% boys and 16.8% girls aged 6-18 years old were obese when the 1993 local standard was adopted, compared to 13.4% and 10.5% in 1993 (Yeung & Hui, 2007). The prevalence of childhood obesity for boys and girls had been increased by 68% and 60% in the past 13 years, respectively.

These reports indicate that the prevalence of childhood obesity in the world is growing, but the criteria of defining childhood obesity are body mass index (BMI), such as BMI-for-age (Ogden et al., 2006; Ogden et al., 2002), and International Obesity Taskforce (IOTF) BMI cutoff (Cole, 2002) or weight-for-height (Leung, Lau, Tse, & Oppenheimer, 1996a; Leung, Ng, Lau, & Tse, 1995), which is a screening tool of obesity rather than an accurate measurement of fatness in children (Ellis, Abrams, & Wong, 1999; Heyward & Stolarczyk, 1996). Scientists have commented that weight/height ratio is only a crude index of body composition, but it cannot accurately reflect the body fatness of individual. Hence, in order to accurately identify children who are overweight or obese, direct measurement of body fatness is a preferable measure than weight/height index.

Factors Contribute to Childhood Obesity

There are several factors contributing to childhood obesity. According to Nieman (1999), the main factors are genetic and parental influences, high energy intake, and low energy expenditure.

Genetic and Parental Effects

An identical twins study done by Stunkard and colleagues (1990) found that twins reared apart are much more alike in body mass index than expected. Bouchard and colleagues (1988) found that the additive genetic effect for body fatness was between 5% and 25%. Mayer (1965) found that 80% of the children of two obese parents eventually become obese, compared to 14 % when neither parents is obese. These show that the genetic and parental effects had a great influence to obesity of children.

Overeating

High energy diet is another cause of obesity (Nieman, 1999). Many people in western countries are suffering from binge eating. Modern meals in most westernized cities, such as fast food and soft drinks, are rich in fat and sugar. These high-fat and energy-rich foods will convert into body fat in if there is positive energy balance (i.e. energy intake higher than energy expenditure).

Insufficient Physical Activity

According to American Heart Association position stand, "Physical inactivity is a major risk factor for developing coronary artery disease. It also contributes to other risk factors, including obesity, high blood pressure, high triglycerides, a low level of HDL cholesterol and diabetes" (Haskell et al., 2007).

A sedentary person spends 300-800 Calories (in kcal) a day only (Nieman, 1999) compared with 2000 kcal for a healthy person. The excess energy will be converted into body fat and stored in the body. Obesity is developed from prolonged positive energy balance.

The most recent Physical activity recommendation of American College of Sports Medicine and American Heart Association (Haskell et al., 2007) states that healthy individuals should have "moderate-intensity aerobic (endurance) physical activity for a minimum of 30 min on five days each week or vigorous-intensity aerobic physical activity for a minimum of 20 min on three days each week" .

Other factors

Apart the factors mentioned above, Hui and Sum (2007) found that there are strong associations among children television (TV) and computer watching time, body mass index (BMI), and physical activity (PA) participation. More than one hour of TV/Computer watching daily marks a significant increase in BMI and decline in PA participation. The result shows that television and computer watching may promote sedentary lifestyle and thus children are getting positive energy balance and become obese.

Health Consequences

Obesity and overweight pose a major risk for serious diet-related chronic diseases, including abnormal glucose metabolism or type 2 diabetes (American Diabetes

Association, 2000; Freedman, Serdula, & Khan, 2002; Steinberger, Morehead, Katch, & Rocchini, 1995), Sleep-disordered breathing (de la Eva, Baur, Donaghue, & Waters, 2002; Riley, Santiago, & Edelman, 1976), asthma (Gennuso, Epstein, Paluch, & Cerny, 1998; Luder, Melnik, & Dimaio, 1998), cardiovascular disease, hypertension and stroke (Figueroa-Colon, Franklin, Lee, Aldridge, & Alexander, 1997), and certain types of cancer (Freedman et al., 2002). It also affect children psychosocially (Strauss, 2000) The health consequences range from increased risk of premature death, to serious chronic conditions that reduce the overall quality of life. Of especial concern is the persistence of childhood obesity into adulthood. Studies found that many obese children are still obese as adults (Maffeis, Moghetti, Grezzani, Clementi, Gaudino, & Tatò, 2002). Childhood obesity is a risk factor of adult morbidity and mortality (Dietz, 1998; Freedman et al., 2002; Guo & Chumlea, 1999).

Childhood Obesity Interventions

Various projects and campaigns have been initiated in Hong Kong in order to promote healthy lifestyle in children and to tackle the problem of childhood obesity.

Healthy Exercise for All Campaign

In community level, LCSD and DH launched a territory-wide event named "Healthy Exercise for All Campaign" in April 2000. With the slogan of "Daily exercise keeps us fit, people of all ages can do it", the Campaign aims at raising the public's interest in exercising and encouraging them to exercise regularly so that they can understand the benefits of exercising to health. Activities include a weight control program designed for overweight children aged 8-12. The purpose was to educate them to participate in exercise daily, according to the guideline of ACSM. The program consisted of 12 sessions, including teaching of low impact aerobic exercises, such as walking, jogging, and aerobic dance. Lesson content also included basic weight training and other weight control techniques such as diet control.

School Physical Fitness Award Schemes

In school level, EMB, the Hong Kong Childhealth Foundation (HKCHF) and Physical Fitness Association of Hong Kong China (HKPFA) organized the School Physical Fitness Award Scheme. The scheme aims at promoting the awareness of health-related fitness among school children and encouraging them to participate in regular exercises. Students participating in the scheme are required to take physical fitness tests at school and pursue physical activities during their leisure time, including body composition assessments such as height, weight and skinfold measurement. If their results in the tests reach the required level, they will be awarded badges.

These schemes and projects, however, do not have a valid measurement of children body composition. It is difficult to evaluate the effectiveness of these projects, and more importantly, the prevalence of childhood obesity in Hong Kong. It is important to monitor children body composition because of its serious health consequences. There is an urgent need for measuring body composition, so as to evaluate the rate of childhood obesity in Hong Kong. In order to measure and track changes in body composition of children, valid and reliable body composition measurement methods are essential. In the following section, a brief review on measurement methods will be addressed.

Measurement of Body Composition in Children

Body Composition Models

Body mass can be viewed as five levels, which are atomic, molecular, cellular, tissue-organ, and whole-body levels (Wang, Pierson, & Heymsfield, 1992). Most body composition research was performed using the two-component molecular level model over the past decades. In this classic two-component (2-C) model, body mass is partitioned into two components at molecular level, fat mass (FM) and fat-free mass (FFM) (Brozek, Grande, Anderson, & Keys, 1963; Siri, 1961). FFM is considered the actively metabolizing component at the molecular level of body composition. The assumptions of the two-component models are:

1. The density of fat is 0.901 g/cc.
2. The density of fat-free mass is 1.10 g/cc.
3. The densities of FM and FFM are the same for all individuals.
4. The densities of the tissues comprising the FFM are constant within an individual,

and their proportional contribution to the lean component remains constant.

5. The individual being measured differs from the reference body only in the amount of fat. The FFM of the reference body is assumed to be 73.8% water, 19.4% protein, and 6.8% mineral.

The density of FFM has been estimated on the basis of limited data from chemical analyses of animal carcasses and human cadavers. (Brozek et al., 1963; Keys & Brozek, 1953; Siri, 1961) Thus, percent body fat can be calculated if we obtain the body density from hydrodensitometry according to following 2-C model equations:

$$\% \text{ Fat} = (4.95 / Db - 4.50)\ 100 \qquad \text{(Siri, 1961)}$$

$$\% \text{ Fat} = (4.570 / Db - 4.142)\ 100 \qquad \text{(Brozek et al., 1963)}$$

These 2-C model equations are an accurate estimate of percent body fat from body density, as long as the basic assumptions of the model are met. However, the molecular level actually consists of more than two components. There are six components, including water, lipid, protein, carbohydrates, bone minerals, and soft tissues mineral (Shen, St-Onge, Wang, & Heymsfield, 2005). Different multicomponent models thus created that ranged from three components to six components. These models further divide FFM into additional components. For example, in the three-component (3-C) dual energy X-ray absorptiometry (DXA) model, FFM consists of bone minerals and lean soft tissues.

Recent advances in technology allow measurement of fat-free components like body water, mineral and protein by means of isotope dilution, DXA and neutron activation analysis, respectively. The use of multicomponent models reduces errors. Siri (1961) found that the use of its 3-C equation would decrease the percent-fat error from 4% based on body density alone to 2% for density and water.

Evidence revealed that fat-free body density varies with age, gender, ethnicity, level of body fatness, and physical activity level (Billisari & Roche, 2005; Heyward, 2006). The density of FFM of the Blacks greater (~1.106 g cc^{-1}) than 1.10 g cc^{-1} because of their higher mineral content (Cote & Adams, 1993; Ortiz et al., 1992; Wagner & Heyward, 2001). In order to avoid systematic error in estimating body fat of children by using 2-C model equations, scientists have applied multicomponent models based on bone mineral and total body water. The "reference man" of the original 2-C model was replaced by population-specific reference bodies that take into account of age, gender, and ethnicity. Age and population-specific equations for converting body density to percent body fat were created.

However, there are no population-specific conversion formulas available for Asian children. In this case, Heyward (2006) suggested that researchers may use the age-specific equations developed for White children. The equations are:

$$\% \text{ Fat} = (5.27 / \text{Db} - 4.85)\ 100 \qquad \text{for boys aged 8-12}$$

$$\% \text{ Fat} = (5.27 / Db - 4.85)\ 100 \qquad \text{for girls aged 8-12}$$

$$\% \text{ Fat} = (5.12 / Db - 4.69)\ 100 \qquad \text{for boys aged 13-17}$$

$$\% \text{ Fat} = (5.19 / Db - 4.76)\ 100 \qquad \text{for girls aged 13-17}$$

Measurement Methods

There are different methods to estimate body composition. Laboratory methods, while precise, usually involve expensive equipment and complex procedures. Field methods, though less accurate compared with laboratory methods, are much simpler and inexpensive. Field measurements can be carried out with large group of people in school or community settings.

Laboratory Methods

Hydrodensitometry

Estimating body volume by hydrodensitometry, or underwater weighing, applies Archimedes' principle. When a subject is submerged in water, the weight of displaced fluid is equals to the "loss" of weight contributed by the buoyancy force acting on the subject. Therefore, the body volume equals to the loss of weight in water (Going, 2005; Lohman, 1992). Corrected for the density of water corresponding to the temperature of the water at the time of submersion:

$$Db = (BWa / BWa - BWw)$$

With the correction with residual lung volume and gastrointestinal tract gas volume, the calculation of body volume becomes:

$$V = [(BWa - BWw) / Dw] - RV$$

Where the residual volume can be measured by oxygen dilution method, or estimated by following equations:

$$\text{MEN:} \quad RV\ (L) = [0.019 \times Ht\ (cm)] + [0.0115 \times Age\ (y)] - 2.24$$

$$\text{WOMEN:} \quad RV\ (L) = [0.032 \times Ht\ (cm)] + [0.009 \times Age\ (y)] - 3.90$$

When the equations are combined, the completed equation for body density is:

$$Db = (BWa \times Dw) / (BWa - BWw) - (RV + 100)$$

Hydrosensitometry is often regarded as the "gold standard" of body fat assessment (Going, 2005; Heyward, 2001, 2006). It is relatively safe and low-cost. However, a number of technical issues make it not feasible for field testing (Going, 2005). These limitations include: a) subject is required to submerge in water, thus making it not suitable for subjects who are not accustom to aquatic activity; b) a large water tank with a spring scale or a digital scale, heater, water circulator and filter are required; c) subject is required to perform maximal expiration underwater in order to obtain the underwater weight; d) it is time-consuming which makes it not convenient for mass testing. Moreover, it has been found that difference exists between percent body fat from hydrodensitometry and four-component (4-C) model. This may due to technical errors in estimating the residual volume (Going, 2005) and conversion from body density to percent body fat based on 2-C model equations.

Air displacement plethysmography

In contrast, air displacement plethysmography (ADP) by Bod Pod (Life Measurement System, Concord, CA) may be a preferable way than other body composition measurement method because of its fast measurement on land. It measures body volume and body density by using pressure-volume relationships (Fields et al., 2002; Going, 2005). The Bod Pod consists of a single structure with two chambers: a test chamber and a reference chamber. During measurement process, the subject is required to sit in the test chamber, with minimal clothing and a swim cap to minimize the isothermal effects related to hair and clothing. Compare with hydrodensitometry, it is a more appropriate body composition method for young children because it is safe and easy to use, and no water submersion is required.

ADP shows good to excellent reliability in measuring humans (Demerath, Guo, Chumlea, Towne, Roche, & Siervogel, 2002). In both children and adults, between-day, test-retest correlation coefficient for body density and percent body fat generally exceeds r = .90. Wells and Fuller (2001) reported the precision of percent body fat to be 0.83% and 0.99% for boys and girls, respectively. In the study, it also found that precision was not related to body size because the precision for duplicate measurements in men and woman (0.99% and 0.76% body fat) was similar to children. Dewit and colleagues (2000) found that the precision of body volume measurements in children 7 to 14 years was 0.07L, which was as good as the precision for adults in the same study. These reports show that the precision of body volume measurement in children was as good as the precision of adults.

ADP has been validated for the use with adults and demonstrated good precision when compared with hydrodensitometry, dual energy X-ray absorptiometry, and multicomponent models (Dewit et al., 2000; Fields & Goran, 2000; Fields et al., 2002). In children, the average difference between percent body fat estimated from hydrodensitometry and Bod Pod range from -2.9% to 1.2% body fat (Dewit et al., 2000). Fields and Goran (2000) found that the regression relationship of fat mass by ADP and four-compartment model did not significantly deviate from the line of identity, indicating that it is a valid estimate of FM without bias for children age 9-14 years. The results of these available studies support ADP as a reasonable alternative to hydrodensitometry (Going, 2005). Therefore, ADP would be a desirable means to obtain the criterion measure of body fat for children.

Hydrometry

Hydrometry is the measurement of total body water (TBW) (Heyward, 2001; Lohman, 1992; Schoeller, 2005). Stable isotope labeled water, such as deuterium or oxygen-18, are commonly used. The concentration of these hydrogen isotopes in biological fiulds after equilibration is measured to determine TBW.

In the absence of measures other than weight, the most common and useful body composition model is the 2-C model of FM and FFM (Lohman, 1992). The calculation of FFM from body water depends on an assumption of constant hydration of FFM. The most commonly used hydration constant is 0.73, which was first recommended by Pace and Ratbun (1945) and confirmed by other studies (Keys & Brozek, 1953; Knight, Beddoe, Streat, & Hill, 1986; Moore, Lister, Boyden, Ball, Sullivan, & Dagher, 1968). It can also subdivided into intercellular and extracellular water by bromide dilution (Schoeller, 2005).

In children, FFM hydration is a maximum from birth (~0.8) and declines rapidly during first few years to ultimately reach ~0.73 during teenage years (Sopher, Shen, & Pietrobelli, 2005). The isotope dilution method may not be the optimal method for assessing total body fat in children because of the wide variation in the hydration of FFM between individuals (Hashimoto et al., 2002; LaForgia, van der Ploeg, Withers, Gunn, Brooks, & VChatterton, 2004), but they are the most reliable approach for estimating TBW (Sopher et al., 2005). LaForgia and colleagues (2004) found that the 3-C model (FM, TBW and fat-free dry solid) produced FFM values that were not significantly different from the four-component (4-C) estimates, which showed better results than the 2-C model which use hydrodensitometry alone. This shows that if complementing hydrometry with densitometry, these multicomponent models will be a better estimate of body density than the 2-C model (Lohman, 1992), as the variation of body water is taken into account.

Dual energy X-ray absorptiometry

Dual energy X-ray absorptiometry (DXA) is originally a means of measuring bone mineral density (BMD). Two X-ray beams with differing energy levels are aimed at the participant's bones. BMD can be determined from the absorption of each beam by bone when soft tissue absorption is subtracted out. DXA is the most widely used and most thoroughly studied bone density measurement technology. DXA scans can also be used to measure total body fat and lean body content. Previous studies reported the correlation of DXA and hydrodensitometry were satisfactory (Lohman & Chen, 2005; Van Loan & Mayclin, 1992).

Because of its lower amount of radiation exposure, DXA is a safe method to assess pediatric body composition. It is an alternative to the four-component model in pediatric population as it measures bone mineral content, lean soft tissue, and fat directly (Lohman & Chen, 2005). Sopher and colleagues (2005), however, found that measurements by DXA are not equivalent to those of the four-component model. They suggested that the difference in pattern is due to calibration differences between different DXA system manufacturers. It is a problem concerning using DXA is standardization between DXA instruments. Difference in software, hardware, and boundary used during measurement results difference in the estimated percent body fat (Norcross & Van Loan, 2004; Soriano, Ioannidou, Wang, Thronton, Horlick, & Gallagher, 2004). Standardization between manufacturers and validation of equations using multi-component model is needed (Lohman & Chen, 2005).

There are other laboratory methods to measure body composition, such as neutron activation analysis, computed tomography and magnetic resonance imaging (Ellis, 2005; Ross & Janssen, 2005). These methods are able to produce images with high resolution. However, the procedures are not standardized. Moreover, they involve very expensive equipments and technical skill. Radiation exposure is also a concern for these methods.

Pros and cons of body fat criterion measures

Both hydrodensitometry, ADP and hydrometry, when using alone, applies the 2-C molecular level model, while DXA applies the 3-C tissue level model (Heyward, 2006; Lohman, 1992). For most accurate measurement, these methods should be used together for obtaining Db, bone mineral density and TBW with the multicomponent model.

Compare with other laboratory methods, the ADP method is a more desirable body composition method for young children because it is safe and easy to use. More importantly, no water submersion is required. Body fatness can be measured within just a few minutes. ADP also has no standardization issue like that of DXA (Lohman & Chen, 2005; Norcross & Van Loan, 2004; Soriano et al., 2004). A number of studies indicate that the accuracy of body fat measurement using the ADP method is comparable to those obtained by underwater weighing and four-compartment model (Dewit et al., 2000; Fields & Goran, 2000; Fields et al., 2002; Going, 2005). Therefore, ADP would be a desirable means to obtain the criterion measure of body fat for children.

Field methods

In field setting, the laboratory methods mentioned in previous section are not practical, because they require sophisticated equipment and skills as described above. Field methods are thus developed to measure body fat in a more efficient and more economical way.

Bioelectric impedance analysis

The principle of bioelectric impedance analysis (BIA) is based on the relation of body composition to the body water content (Hoffer, Meador, & Simpson, 1969; Nyboer, 1959). With this method, low-level electrical current is passed through the subject's body, and the impedance, or resistance of current, is measured by an analyzer. Impedance will be greater for subject with more body fat, as adipose tissue is a poor conductor of electricity. Total body water is estimated and so fat-free mass can be predicted.

Although BIA is a non-invasive and fast method for measuring body composition, its precision is affected many factors, including body position, hydration status, food or beverage consumption, ambient air and skin temperatures, recent physical activity, and bladder activity. Analyzers from different brands and companies show deviation in result (Graves, Pollock, Colvin, Van Loan, & Lohman, 1989). Validation for the available equations in different systems against acceptable reference methods is required.

Anthropometry

Anthropometry is the measurement of the size and proportion of the human body (Heyward, 2001). It includes body height, body weight and body circumferences.

Body mass index (BMI) is defined as the individual's body weight divided by the square of their height. The unit used in is kg/m^2. In adults, obesity is defined as a BMI of 30 kg/m^2 or more, and overweight is defined as a BMI between 25 and 29.9 kg/m^2; while for Asian, the cut off is 25 kg/m^2 and 23 kg/m^2 (World Health Organization, 2004). In children, Cole and colleagues (2000) established an international BMI cutoff for childhood overweight and obesity, which the cut off points were extrapolated from adult BMI cut off of 25 kg/m^2 and 30 kg/m^2 for overweight and obesity.

Weight-for-height index has been used in Hong Kong since 1993 (Leung, 1995; Leung et al., 1996a; Leung et al., 1995; Leung et al., 1996b). Since that time, childhood obesity has been defined as having a body weight 20 percent higher than the median weight of the same height (i.e. 120% weight-for-height). Using this definition, data of the 1993 Hong Kong Growth Survey (Leung et al., 1996a) was used as local reference to determine the criteria for the cut off points of childhood obesity until now.

Before the Hong Kong Growth Survey was available, National Center for Health Statistics (NCHS) reference (Hamill, Drizd, Johnson, Reed, & Roche, 1977) and Singapore School Health Service Standards (Ministry of Health, 1992) were used to define childhood obesity, and the 120% weight-for-height criteria were already adopted at that time. However, these references were not local and did not cover the age from birth to 18 years.

The use of these weight-height indices to represent body fatness is limited, even though BMI is a predictor of cardiovascular disease and type 2 diabetes (Janssen, Heymsfield, Allison, Kotler, & Ross, 2002). It is because it does not account for the composition of body weight (Heyward, 2006). Persons having same BMI or weight-for-height in fact may have difference in body composition.

Waist circumference is also a good measure of abdominal obesity (Heyward, 2006). The American College of Sports Medicine (2005) recommends using waist circumference cut off of 102 and 88 for men and women, respectively; or gender neutral value of >100 cm to evaluate obesity as a risk factor for coronary heart disease.

Skinfold thickness measurement

Scientists suggest the use of skinfold method in field setting as an alternative of laboratory method. Currently skinfold measurement is the most widely adopted field method of body fat measurement in children (Heyward, 2006). Since the instruments are portable, inexpensive and non-invasive, skinfold method can be readily applied in clinics, laboratories and schools. It is a measure of the thickness of two layers of skin and the underlying subcutaneous fat. It can be applied in both laboratory and field situations. It is a classic yet still widely applied body composition measurement method. The skinfold method indirectly measures the thickness of subcutaneous adipose tissue. Usually, skinfold thicknesses of different sites are collected.

According to Heyward and Stolarczyk (1996), there are several basic assumptions when using the skinfold method to estimate total body density to derive percent body fat:

1. The skinfold method is a good measure of subcutaneous fat.
2. The distribution of fat subcutaneously and internally is similar for all individuals within each gender.
3. There is a relationship between subcutaneous fat and total body fat, the sum of several skinfolds therefore can be used to estimate total body fat.

Skinfold thicknesses have high correlations with percent body fat ($r = .7$-$.9$) and do not differ among the common sites (Billisari & Roche, 2005). The distributions of adipose tissue and body proportion of children, however, differ from those of adults. Therefore, the prediction equations used to estimate percent body fat of adults are different than that used to estimate the fatness of children. Skinfold thickness measurements in children, with appropriate validated prediction equations, can be used to estimate body density and percent body fat (Sopher et al., 2005). Percent body fat estimated by these equations correlates well with percent body fat that determined by hydrostatic weighing (Harsha, Frerichs, & Berenson, 1978). Moreover, it is better predictor of body density than body circumference in children (Billisari & Roche, 2005).

The validity and reliability of skinfold method are affected by technician's skill, type of skinfold caliper, subject factor, and prediction equation used to estimate body fatness (Lohman, Pollock, Slaughter, Brandon, & Boileau, 1984). Standardized skinfold sites and procedures are recommended in the testing guidelines by ACSM (2005).

Slaughter equations

Slaughter equations (Slaughter et al., 1988) are commonly used pediatric skinfold equations which uses multicomponent model reference measures. These equations may be used to assess the body composition of African American and Caucasian children aged 8 to 17 years old. They utilize the sum of triceps and calf skinfolds to predict the percent body fat of children. The equations are:

$$\text{BOYS:} \quad \%BF = 0.735\ (\sum 2SKF) + 1.0$$

$$\text{GIRLS:} \quad \%BF = 0.610\ (\sum 2SKF) + 5.1$$

The prediction error for these equations ranged from 3.6 to 3.9 % body fat (Heyward & Stolarczyk, 1996; Slaughter et al., 1988). The concept leading to the development of the Slaughter equations is that adult skinfold equations tend to overestimate body fatness in children, and its multicomponent approach take chemical immaturity of children into account, since the chemical composition of the fat-free body will change as children pass through puberty (Slaughter et al., 1988).

Some studies (Gaskin & Walker, 2003; Janz, Nielsen, Cassady, Cook, Wu, & Hansen, 1993; Lohman & Going, 1998; Magarey, Daniels, Boulton, & Cockington, 2001) suggested the use of triceps and subscapular site would be more useful and has less error than the triceps and calf equations when estimating the percent body fat of adolescents. Janz and colleagues (1993) found that the triceps and calf equation for girls slightly overestimated the average percent body fat by 1.7%, and that for boys had a large percentage error (SEE = 4.6% percent body fat) and varied with maturation level. Nevertheless, Heyward and Stolarczyk (1996) suggested using Slaughter equations so as to minimize physical contact with the child during measurement, especially for young adolescent females, as taking measurement at the calf site would be more acceptable than subscapular site.

At the moment, the Slaughter equations are the most widely used equations for pediatric measurement. However, the Slaughter equations are not valid to use on Hong Kong children. It is because these prediction equations are age and race specific, which mean cross-validation is required before applying these equations in new populations

(Ellis, 1998). Local studies found large error when applying the Slaughter's skinfold equations on Chinese children. Hui and associates (2001) reported that percent body fat estimated from the Slaughter equations shared small variances with the criterion with large standard error of estimate (boys: $R^2 = .25$, SEE = 8.02%; girls: $R^2 = .21$, SEE = 6.71%) . Another local study found that the Slaughter equations underestimated a mean of 2.3% body fat, but significant correlations ($r = .825$, $p < .01$) between these two estimates were found. The authors concluded that the sum of 3 skinfolds could provide more accurate estimate than the Slaughter equations in assessing percent body fat in Chinese boys aged 6 to 12, if time and resource are available. (Louie, Chow, & Kong, 2001)

Regardless there is a lack of validated skinfold equations for estimating body fatness of Chinese children in Hong Kong (Hui et al., 2001), skinfold measurement of Hong Kong school children has been collected for many years. Practitioners in Hong Kong simply adopt the sum of skinfolds to get a rough idea of body fatness, or the Slaughter's equations to get an estimation of body fatness which is considered erroneous. Therefore, there is an urgent need to develop a validated skinfold equations for estimating body fatness of Chinese children in Hong Kong. To do that, measurements of skinfold thickness from various sites of Hong Kong Chinese children, and criterion measures of body fatness such as those obtained from hydrodensitometry or ADP are needed.

Summary

The prevalence of childhood obesity in Hong Kong has increased closed to 70% in the past 13 years. However, question has been raised about the definition of childhood obesity using the weight/height ratio which has been adopted since 1993. For tracking the childhood obesity level effectively, there is an urgent need to evaluate the obesity level of children in Hong Kong using objective and practical measurement. To achieve this, examination of the validity and reliability of skinfold measurement in predicting the body density and body fatness of children in Hong Kong is needed.

Laboratory methods of body composition, including hydrodensitometry, ADP, hydrometry and DXA, provide accurate measurement, but not feasible due to involvement of sophisticated equipments and complex procedures and trained technicians. Field methods, including bioelectric impedance analysis, anthropometry, and skinfold measurement method, though less accurate compared with laboratory methods, are much simpler and inexpensive, and can be carried out with large group of people in community or school settings.

The skinfold method is the most widely adopted field method of body fat measurement. It is an alternative to laboratory methods and has high correlation with percent body fat. However, only the Slaughter equations have been developed which has not been validated for Chinese children. In order to obtain accurate evaluation of body composition of Hong Kong children, there is a need to examine the validity and reliability of skinfold measurement in predicting body density and percent body fat of Chinese children in Hong Kong.

METHODOLOGY

Participants

230 healthy voluntary Chinese children, aged 9-19 year-old (142 boys and 88 girls) were recruited. A stratified purposeful sampling method was used to recruit a heterogeneous sample that covers a wide range of age and body composition according to their age and gender specific BMI distribution among HK children (Hui, 2005).

The purpose, risks and benefits were explained to each participant and their parents before obtaining written informed consent. Medical history of participants was collected. Ethical approval was sought from the Ethical Committee for Conducting Research Using Human.

Experimental protocols and procedures

Criterion Measurement

ADP was performed using the Bod Pod (Life Measurement System, Concord, CA) according to the manufacturer's instructions and recommendations. Participants were required to wear a tight fitting swimsuit and swimming cap. Participants were weighed to the nearest 0.1 kg on a calibrated electronic scale, and height was determined by a stadiometer to the nearest centimeter. Body volume was measured using ADP. According to Fields and colleagues (2002), the measurement involves three steps. The first step was the standard 2-point calibration process with the chamber empty to establish baseline and then with a calibration cylinder to establish range. This procedure involved a volume calibration with and without a 50 litre metal cylinder.

In the second step, participant was required to sit in the test chamber and the volume of the participant in the chamber is measured. Subjects entered the Bod Pod and sat inside the anterior chamber (450 litres), which was connected to a rear-measuring chamber (300 litres) via oscillating diaphragms (used to induce pressure changes in the anterior chamber), and breathed normally (relaxed tidal breathing). The recommended procedure, consisting of two measurements of body volume (50 seconds each), was adopted and when body volumes differed by more than 150 ml, the system required that a third measurement be performed. The final result reported by the Bod Pod instrumentation was the mean of the two (or the two closest) measurements.

In the third step, thoracic gas volume was estimated. Finally, the corrected body volume and so body density and percent body fat (%fat) was calculated by the Bod Pod with well established equations (Fields et al., 2002).

Comparison of Percent Fat Criterion by ADP and DXA

A sub-sample of 41 participants was taken the DXA measurement. A fan beam Dual Energy X-Ray Densitometer (Hologic QDR 4500, USA) was used. According to the operators' manual, it uses a low level of X-rays with two different energies to estimate BMC, BMD and %fat. For the scanning process, the operator exposure is less than 1 mR/hour at a distance of 1.6 meters from the X-ray source. No additional shielding is necessary for the patient, operator, or room.

The body composition measured by DXA was used to compare with the ADP criterion in this study. The mean difference between percent body fat measured by ADP ($\%fat_{ADP}$) and that measured by DXA ($\%fat_{DXA}$) was compared.

Field Measurements

Body height was measured by a calibrated wall-mounted stadiometer (Holtain Ltd., U.K.). A calibrated electronic digital balance scale (Model TBF-401, Tanita, Japan) was used to measure the body mass of participants. During height and weight measurements, participants were required to wear minimal clothing with bare feet. Waist circumference was measured at the narrowest part of the torso, above the umbilicus and below the xiphoid process using a Gulick Tape. Harpenden caliper (U.K.) was used to measure participants' skinfold of different body sites, including triceps, subscapular, suprailiac, abdomen, thigh, and calf. It was measured according to the standard procedures prescribed by the guidelines of American College of Sports Medicine (American College of Sports Medicine, 2005). The guidelines are:

1. All measurements should be made on the right side of the body.
2. Caliper should be placed 1 cm away from the thumb and finger, perpendicular to the skinfold, and halfway between the crest and the base of

the fold.

3. Pinch should be maintained while reading the caliper.
4. Wait 1 to 2 seconds (and not longer) before reading caliper.
5. Take duplicate measures at such side and retest if duplicate measurements are not within 1 to 2 mm.
6. Rotate through measurement sites or allow time for skin to regain normal texture and thickness.

Specific description of all the skinfold measurements is displayed in Appendix A. These measurements were undertaken immediately before ADP.

Statistical Analysis

Means and standard deviation was computed to describe the study sample. Age-adjusted correlation was used to determine the relationship between body density and percent body fat with different variables, including weight, height, BMI, waist circumference, arm circumference, and skinfold of different sites. Repeated *t*-tests were used for mean comparisons between $\%fat_{ADP}$ and $\%fat_{DXA}$, and between $\%fat_{ADP}$ and estimated %fat from various SKF equations. The effect sizes for these differences were computed to determine the importance of the mean differences.

The internal consistency of ADP and skinfold measurement were examined using intraclass correlation coefficients. Multiple regression models were used to examine the criterion-related validity of skinfold measurement in predicting body density and %fat derived from ADP. R-square and standard error of estimates were computed from regression analysis to examine the accuracy of the prediction. Meanwhile, Bland-Altman plots (Bland & Altman, 1986) were produced to illustrate the residual errors of the Slaughter equations and the proposed regression models.

All analyses were conducted using SPSS 12.0, and results were considered statistically significant at $p < .05$.

RESULTS

Comparison of ADP and DXA in Measuring Percent Fat Criterion

The percent body fat measured by DXA (%fat_{DXA}) was used to compare with that measured from ADP criterion (%fat_{ADP}) in this study. The result of repeated *t*-test is shown in Table 1. It showed that there was no significant difference ($t = 0.15$, df = 40, $p > .05$) between %fat_{ADP} and %fat_{DXA}, The computed effect size for the difference was .25. These suggested that ADP could be an acceptable criterion of measuring %fat in this study.

Table 1
Repeated t-test showing the difference between %fat_{ADP} and %fat_{DXA} ($n = 41$).

Method of measurement	Mean	Standard deviation	SEM	*r*	*t*	df	*p*
ADP	23.13	9.29	1.45	.92	-0.15	40	.88
DXA	23.22	7.82	1.22				

Note. ADP: Air-diaplacement plethysmography; DXA: Dual-energy X-ray absorptiometry. SEM: Standard error of mean.

Sample Distribution and Descriptive Statistics

As the purpose of the study was to examine the validity and reliability of skinfold measurement for Chinese children in HK, a sample with diverse body composition of children was required in order to achieve the purpose. The age and BMI distributions of the participants are shown in Table 2. A heterogeneous sample (N = 230) with a wide age range (9-19 years) and body composition [BMI ranged from 13.85 to 37.39 (mean ± SD = 20.69 ± 4.46) for boys and 14.16 to 27.67 (mean ± SD = 19.56 ± 2.69) for girls] was recruited.

Table 2

Age and BMI distributions of the participants (N = 230).

Age Group (years)	Boys (n: 142)			Girls (n: 88)			Total
	Low BMI (BMI<30%)[1]	Moderate BMI (30%≥BMI ≥70%)[2]	High BMI (BMI>70%)[3]	Low BMI (BMI<30%)[1]	Moderate BMI (30%≥BMI ≥70%)[2]	High BMI (BMI>70%)[3]	
9-11	9	10	10	1	6	7	43
12-14	13	10	15	6	12	9	65
15-16	4	11	16	7	14	7	59
17-19	12	15	17	6	9	4	63
Total	38	46	58	20	41	27	230

Note. [1]BMI lower than 30^{th} percentile of their age and gender specific BMI distribution among Hong Kong children. [2]BMI between 30^{th} percentile and 70^{th} percentile of their age and gender specific BMI distribution among Hong Kong children. [3]BMI higher than 70^{th} percentile of their age and gender specific BMI distribution among Hong Kong children.

The descriptive statistics of the physical characteristics of the participants are presented in Table 3. The mean percent body fat measured by ADP (%fat_{ADP}) was 19.73 ± 10.62 % for boys and 25.81 ± 6.19 % for girls. Both the mean %fat and skinfolds of different sites of girls were higher than that of boys.

The mean percent body fat estimated by Slaughter skinfold equation (%$fat_{Slaughter}$) was 18.20 ± 8.58 % for boys and 23.97 ± 4.69 % for girls.

Table 3

Descriptive Statistics of the Physical Characteristics of Participants

	Boys (n=142)			Girls (n=88)			Total (n=230)		
	Mean	Range		Mean	Range		Mean	Range	
	(±*SD*)	Lower	Upper	(±*SD*)	Lower	Upper	(±*SD*)	Lower	Upper
Age (years)	14.37	9	19	14.48	9	18	14.41	9	19
	(2.81)			(2.42)			(2.66)		
Height (cm)	161.17	131.1	185.0	156.24	129.2	172.4	159.29	129.2	185.0
	(13.99)			(8.67)			(12.45)		
Weight (kg)	54.79	23.80	111.40	48.00	26.20	74.60	52.19	23.80	111.40
	(16.91)			(8.80)			(14.71)		
BMI (kg/m^2)	20.69	13.85	37.39	19.56	14.46	27.67	20.26	13.85	37.39
	(4.46)			(2.69)			(3.91)		
Body density (kg/l)	1.0499	.984	1.090	1.0346	.999	1.065	1.0440	984	1.090
	(0.0248)			(0.0131)			(0.0223)		
%fat$_{ADP}$ (%)	19.72	2.5	50.4	25.81	12.2	40.8	22.05	2.5	50.4
	(10.62)			(6.19)			(9.63)		
%fat$_{Slaughter}$ (%)	18.20	8.28	41.50	23.97	15.96	37.55	20.41	8.28	41.50
	(8.58)			(4.69)			(7.85)		
Arm C (cm)	23.61	15.9	40.5	22.54	17.1	29.6	23.20	15.9	40.5
	(4.33)			(2.56)			(3.78)		
Waist C (cm)	70.72	49.0	112.0	64.65	49.9	82.5	68.40	49.0	112.0
	(12.51)			(6.11)			(10.92)		
Triceps skinfold (mm)	11.91	4.6	28.8	16.37	8.9	27.1	13.62	4.6	28.8
	(5.85)			(4.31)			(5.73)		
Biceps skinfold (mm)	7.21	2.8	20.2	9.42	4.3	21.2	8.06	2.8	21.2
	(4.09)			(3.28)			(3.94)		
Subscap skinfold (mm)	13.02	4.4	39.0	13.91	5.1	34.0	13.36	4.4	39.0
	(8.517)			(4.93)			(7.36)		
Suprailiac skinfold (mm)	9.47	3.3	37.6	12.60	3.9	36.8	10.67	3.3	37.6
	(7.05)			(5.06)			(6.54)		
Thigh skinfold (mm)	15.35	4.8	38.6	20.90	8.7	38.5	17.48	4.8	38.6
	(8.23)			(5.85)			(7.87)		
Calf skinfold (mm)	11.49	4.7	27.4	14.57	7.9	26.1	12.67	4.7	27.4
	(6.17)			(4.04)			(5.65)		

Note. Arm C: Arm circumference, Waist C: Waist circumference.

Correlations

Correlations between different variables were generated so as to further understand their inter-relationship. As the sample in this study covered a wide range of age, age was thus controlled when correlations between $\%fat_{ADP}$ criterion and different body composition measurements were computed. The results are shown as correlation matrices, which are shown in Table 4 (boys) and Table 5 (girls) respectively. All SKF measurements correlated high with each other. Significant high to very high correlations (r = .636 to .875) were found between $\%fat_{ADP}$ and all SKFs. In both genders, $\%fat_{ADP}$ correlated highest with triceps (r = .875 for boys and r = .798 for girls). It was followed by calf for boys (r = .850) and biceps for girls (r = .711).

Significant high to very high correlations (r = -.644 to -.868) were found between Db and all SKFs. In both genders, Db correlated highest with triceps (r = -.868 for boys and r = -.792 for girls). It was followed by calf for boys (r = -.845) and biceps for girls (r = .704).

Table 4

Age-adjusted Correlation matrix between %fat$_{ADP}$ and body composition measurements for boys

	%fat$_{ADP}$	Db	BMI	Height	Weight	Waist C	Arm C	Triceps	Biceps	Subsc-apular	Supra-iliac	Thigh	Calf
%fat$_{ADP}$	1.000	-.998	.820	.075	.698	.815	.774	.875	.815	.825	.834	.819	.850
Db	-.998	1.000	-.814	-.057	-.689	-.807	-.764	-.868	-.809	-.815	-.830	-.814	-.845
BMI	.820	-.814	1.000	.274	.930	.962	.955	.865	.813	.891	.816	.767	.819
Height	.075	-.057	.274	1.000	.582	.365	.386	.176	.134	.235	.196	.003	.202
Weight	.698	-.689	.930	.582	1.000	.932	.938	.777	.719	.821	.733	.632	.747
Waist C	.815	-.807	.962	.365	.932	1.000	.944	.866	.833	.898	.819	.750	.816
Arm C	.774	-.764	.955	.386	.938	.944	1.000	.840	.802	.864	.769	.735	.796
Triceps	.875	-.868	.865	.176	.777	.866	.840	1.000	.886	.885	.779	.873	.884
Biceps	.815	-.809	.813	.134	.719	.833	.802	.886	1.000	.883	.748	.823	.845
Subsc-Apular	.825	-.815	.891	.235	.821	.898	.864	.885	.883	1.000	.803	.803	.825
Supra-Iliac	.834	-.830	.816	.196	.733	.819	.769	.779	.748	.803	1.000	.704	.759
Thigh	.819	-.814	.767	.003	.632	.750	.735	.873	.823	.803	.704	1.000	.870
Calf	.850	-.845	.819	.202	.747	.816	.796	.884	.845	.825	.759	.870	1.000

Table 5

Age-adjusted Correlation matrix between %fat$_{ADP}$ and body composition measurements for girls

	%fat$_{ADP}$	Db	BMI	Height	Weight	Waist C	Arm C	Triceps	Biceps	Subsc-apular	Supra-iliac	Thigh	Calf
%fat$_{ADP}$	1.000	-.994	.685	-.070	.546	.661	.629	.798	.711	.636	.649	.656	.697
Db	-.994	1.000	-.687	-.100	-.534	-.668	-.618	-.792	-.704	-.644	-.657	-.667	-.681
BMI	.685	-.687	1.000	.000	.850	.834	.892	.784	.752	.756	.743	.667	.527
Height	-.070	-.100	.000	1.000	.516	.164	.224	-.061	.082	-.035	-.037	-.138	.073
Weight	.546	-.534	.850	.516	1.000	.789	.873	.630	.687	.610	.599	.490	.481
Waist C	.661	-.668	.834	.164	.789	1.000	.780	.669	.738	.742	.793	.545	.438
Arm C	.629	-.618	.892	.224	.873	.780	1.000	.766	.801	.701	.683	.601	.546
Triceps	.798	-.792	.784	-.061	.630	.669	.766	1.000	.822	.746	.691	.681	.687
Biceps	.711	-.704	.752	.082	.687	.738	.801	.822	1.000	.693	.658	.579	.569
Subsc-Apular	.636	-.644	.756	-.035	.610	.742	.701	.746	.693	1.000	.835	.666	.497
Supra-Iliac	.649	-.657	.743	-.037	.599	.793	.683	.691	.658	.835	1.000	.667	.453
Thigh	.656	-.667	.667	-.138	.490	.545	.601	.681	.579	.666	.667	1.000	.659
Calf	.697	-.681	.527	.073	.481	.438	.546	.687	.569	.497	.453	.659	1.000

Note. Db: Body density; Arm C: Arm circumference, Waist C: Waist circumference.

Reliability

The internal consistency of skinfold measurement and body volume, body density and %fat measured from ADP is summarized in Table 6. As can be seen from Table 6, the correlations of between-trial skinfold measurements of triceps, biceps, subscapular, suprailiac, thigh and calf were .996, .993, .993, .988, .993 and .990, respectively, showing that the internal consistency of skinfold measurements were very high. The correlation between two body volume measurements from ADP was 1, and that between both Db estimations and %fat estimations were .991, showing that the internal consistency of ADP was very high.

Table 6

Internal consistancy for body composition data.

	N	Trial	Mean	SD	*r*
Skinfold measurement					
Triceps	230	1	13.58	5.72	.996
		2	13.62	5.70	
Biceps	230	1	8.00	3.93	.993
		2	8.10	3.96	
Subcsapular	230	1	13.36	7.38	.993
		2	13.30	7.23	
Suprailiac	230	1	10.75	6.87	.988
		2	10.62	6.44	
Thigh	230	1	17.62	8.00	.993
		2	17.44	7.84	
Calf	230	1	12.70	5.61	.990
		2	12.65	5.79	
ADP measurement					
Body volume	230	1	48.31	14.13	1
		2	48.29	14.12	
Body density	37	1	1.0441	0.0185	.991
		2	1.0447	0.0193	
%fat	37	1	21.98	21.98	.991
		2	21.76	21.76	

Cross Validation of Slaughter equations

Validity of the Slaughter equations was evaluated in several ways. Repeated *t*-test was computed and the *t*-table is shown in Table 7. It revealed significant difference between $\%fat_{Slaughter}$ and $\%fat_{ADP}$ ($p < .01$). The computed effect size indices for these differences were .32 for boys and .49 for girls respectively. The Slaughter equations slightly underestimate %fat of Hong Kong children than that of ADP, in which 1.52% for boys ($t = -3.83$, $p < .05$) and 1.84% for girls ($t = -4.61$, $p < .05$).

Table 7
Repeated *t*-test showing the difference between $\%fat_{Slaughter}$ and $\%fat_{ADP}$.

Gender	Method	Mean	SD	SEM	*r*	*t*	df	*p*
Boys	Slaughter	18.20	8.58	0.72	.90	-3.83	141	.00
	ADP	19.72	10.62	0.89				
Girls	Slaughter	23.97	4.69	.50	.80	-4.61	87	.00
	ADP	25.81	6.19	.66				

Note. ADP: Air-diaplacement plethysmography; DXA: Dual-energy X-ray absorptiometry. SD: Standard deviation; SEM: Standard error of mean.

The correlation between $\%fat_{ADP}$ and $\%fat_{Slaughter}$ were computed and scatterplots were produced, which are shown in Figure 1 and 2. Regression analysis was performed so as to examine the criterion-related validity of Slaughter equations on estimating $\%fat_{ADP}$ criterion. The regression table is shown in Table 8. The R square ranged from .64 to .81, and the SEE ranged from 3.77% to 4.67%.

Figure 1

Relationship between %fat$_{Slaughter}$ and %fat$_{ADP}$ for boys.

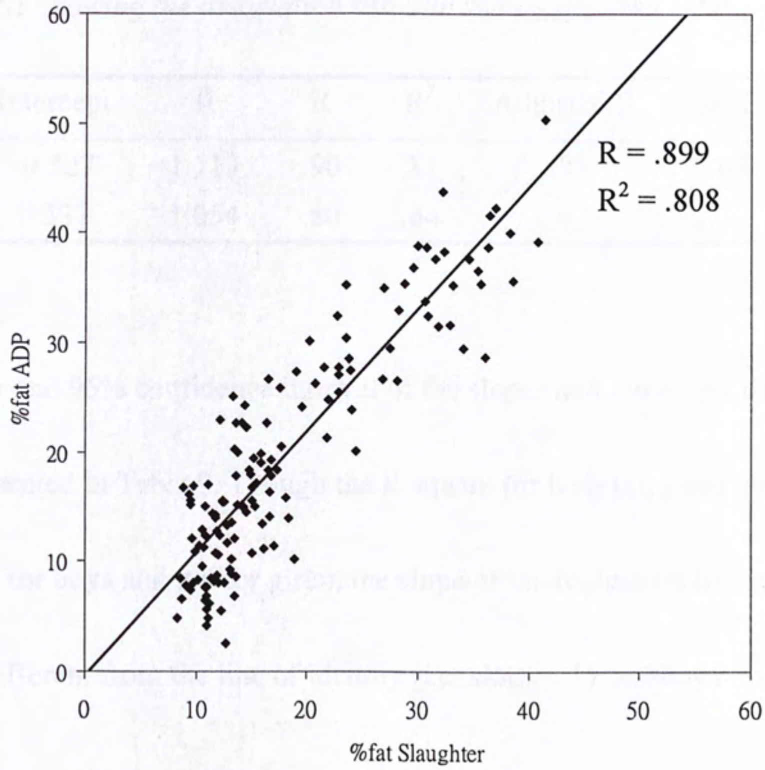


Figure 2

Relationship between %fat$_{Slaughter}$ and %fat$_{ADP}$ for girls.

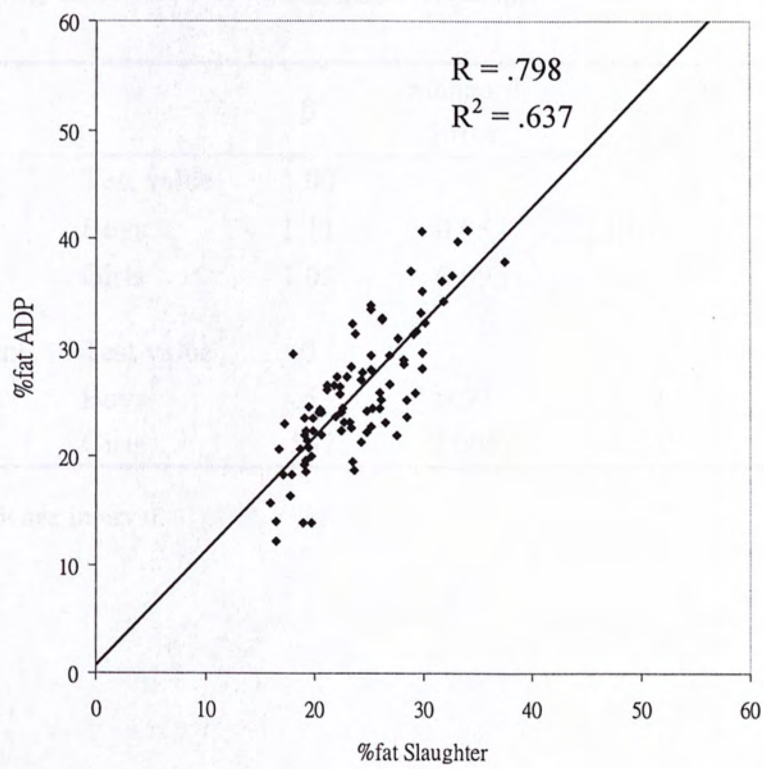


Table 8

Regression table showing the association between %fat$_{Slaughter}$ and %fat$_{ADP}$.

Gender	Intercept	β	R	R^2	Adjusted R^2	SEE	Error
Boys	-0.527	1.113	.90	.81	.81	4.67	4.97
Girls	0.537	1.054	.80	.64	.63	3.77	4.15

The mean and 95% confidence interval of the slopes and intercepts of the regression lines were presented in Table 9. Though the R square for both boys and girls equations were high (.81 for boys and .64 for girls), the slope of the regression line for boys was significantly different from the line of identity (i.e. slope = 1), as shown in Table 9.

Table 9

Description of regression Line of %fat$_{Slaughter}$ vs %fat$_{ADP}$.

		β	Standard Error	95%CI Lower	95%CI Upper
Slope	Test value	1.00			
	Boys	1.11	0.05	1.04	1.22
	Girls	1.05	0.09	0.88	1.23
Intercept	Test value	0			
	Boys	-.53	0.92	-2.37	1.31
	Girls	.537	2.095	-3.65	3.65

Note. CI: Confidence interval.

In order to illustrate how much the estimated %fat from the Slaughter equations were deviated from $\%fat_{ADP}$, Bland-Altman plots (Bland & Altman, 1986) were generated and shown in Figure 3 (boys) and 4 (girls). The Bland-Altman plots illustrated how much $\%fat_{Slaughter}$ were deviated from $\%fat_{ADP}$. The residual (i.e., the difference between the estimated %fat and $\%fat_{ADP}$) are compared to the mean of $\%fat_{ADP}$ criterion and the $\%fat_{Slaughter}$. For the Slaughter equations, 66.9% of the residuals of boys and 78.4% of that of girls fell within 5% body fat.

Figure 3

Bland-Altman plots comparing residuals of Slaughter equation and $\%fat_{ADP}$ for boys.

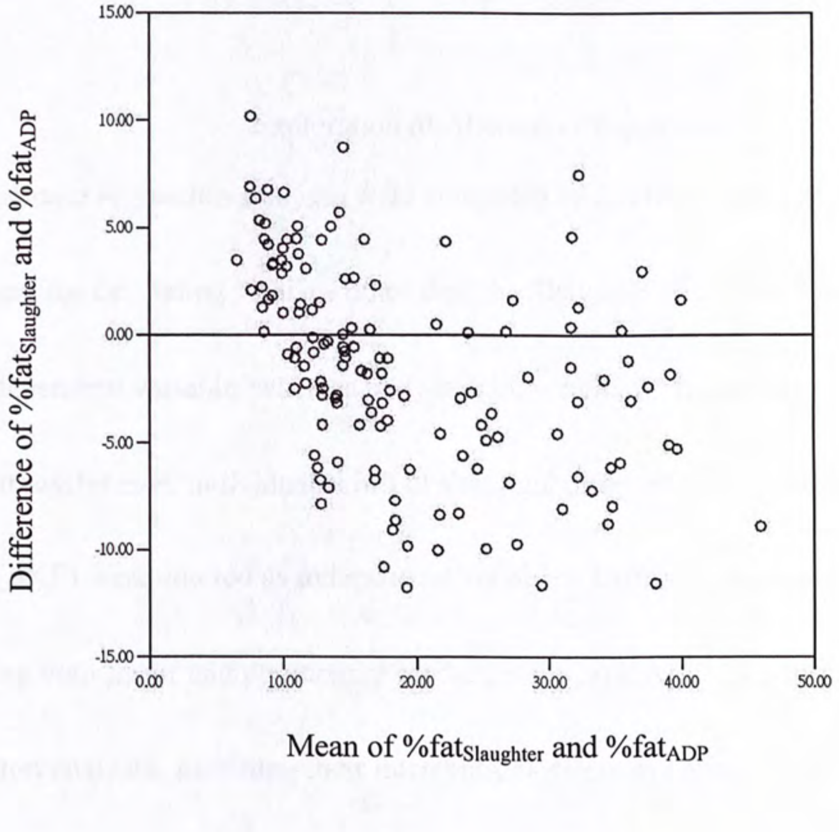
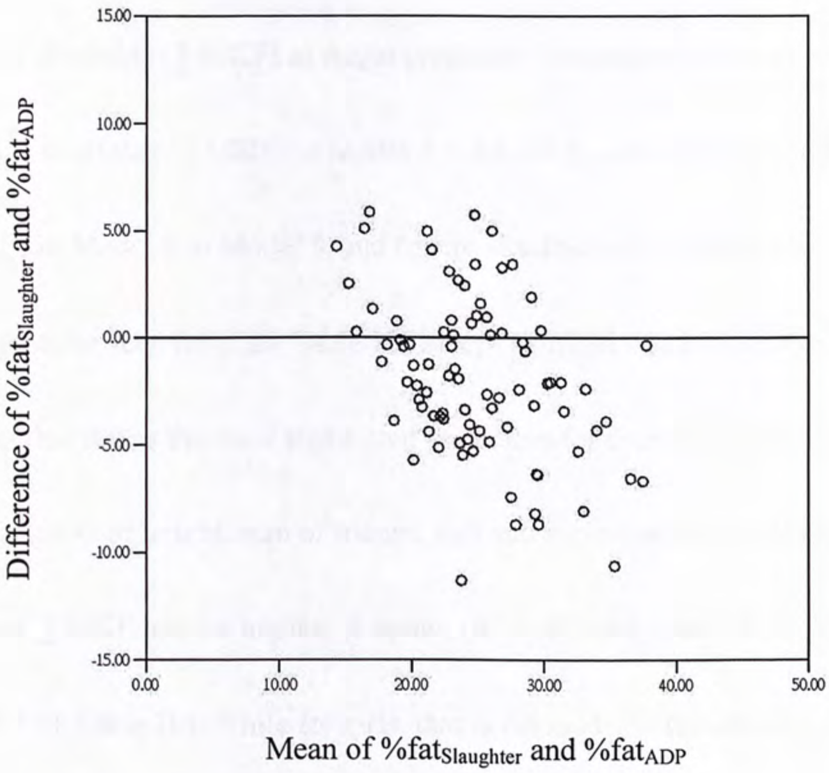


Figure 4

Bland-Altman plots comparing residuals of Slaughter equation and %fat$_{ADP}$ for girls.



Exploration of Alternative Equations

Stepwise regression analyses were computed to determine the best combination of predictors for estimating %fat$_{ADP}$ other than the Slaughter equations. %fat$_{ADP}$ was entered as the dependent variable, whereas body height, weight, BMI, age, arm circumference, waist circumference, individual skinfold sites, and different combinations of skinfold sites ($\sum$SKF) were entered as independent variables. Different regression models, including both linear and polynomial models, were explored. A summary of the regression analyses, including their intercepts, slopes, correlations, R squares, adjusted R squares, standard errors of estimate (SEE) and standard errors, is presented in Table 10.

Only the models with an R square higher than .6 and SEE lower than 5% body fat are included in the table. Model 1 is the model with sum of triceps, biceps, calf and suprailiac skinfolds skinfolds ($\sum$4SKF) as major predictors, compared with sum of triceps, calf and suprailiac skinfolds ($\sum$3SKF) in Model 2 to Model 5, sum of triceps and calf skinfolds ($\sum$2SKF) in Model 6 to Model 8, and triceps skinfold only in Model 9.

As can be seen from the Table 10, triceps skinfold was included in all the models, showing that it was the most significant predictors for estimating $\%fat_{ADP}$. For boys, the model consists of height, sum of triceps, calf and suprailiac skinfolds ($\sum$3SKF) and square of $\sum$3SKF has the highest R square (R^2 = .88) and lowest SEE (SEE = 3.70%) (Model 2 of Table 10). While for girls, that is the model with sum of triceps and calf skinfolds ($\sum$2SKF), height and waist circumference (R^2 = .71, SEE = 3.38%, Model 6 of Table 10). These two models, while accurate, require four body composition measurements, which made them less convenient in practice.

Model 9, which is the model of triceps and age for both genders, is the most convenient model in practice because of its comparable accuracy (R^2 = .81, SEE = 4.67% for boys and R^2 = .64, SEE = 3.77% for girls) and convenience. It consists of one skinfold measurement only, which is the triceps skinfold site. The other models in Table 10, while sharing similar prediction accuracies, were less convenient than the model 9 when adopting them in practical situation.

Table 10

Summary of the Regression Models Estimating %fat$_{ADP}$.

	Model	Gender	Intercept	β	*r*	R^2	Adjusted R^2	SEE
1	∑4SKF + Height	Girls	22.995	.361	.83	.69	.69	3.46
				-.105				
2	**(∑3SKF)^2 + ∑3SKF + Height**	**Boys**	**22.091**	**-.003**	**.94**	**.88**	**.88**	**3.70**
				.760				
				-.147				
3	∑3SKF + Height	Boys	28.566	.530	.94	.88	.88	3.76
				-.163				
4	∑3SKF + Age	Girls	12.463	.448	.82	.68	.68	3.52
				-.426				
5	∑3SKF	Boys	1.828	.545	.91	.83	.83	4.39
		Girls	6.931	.434	.81	.66	.65	3.65
6	**∑2SKF + Height + Waist C**	Boys	27.952	.219	.92	.85	.85	4.13
				.605				
				-.235				
		Girls	**17.539**	**.303**	**.84**	**.71**	**.70**	**3.38**
				.516				
				-.175				
7	∑2SKF + Height	Boys	22.238	.793	.92	.84	.84	4.31
				-.131				
		Girls	23.851	.658	.81	.66	.66	3.63
				-.118				
8	∑2SKF	Boys	.586	.818	.90	.81	.81	4.67
		Girls	5.913	.643	.80	.64	.63	3.75
9	**Triceps + Age**	**Boys**	**14.405**	**1.479**	**.90**	**.81**	**.81**	**4.67**
				-.856				
		Girls	**13.936**	**1.170**	**.80**	**.64**	**.63**	**3.77**
				-.502				

Note. ∑2SKF: sum of triceps and calf skinfolds; ∑3SKF: sum of triceps, calf and suprailiac skinfolds; ∑4SKF: sum of triceps, biceps, calf and suprailiac skinfolds; Waist C: waist circumference; *β*: slope.

The regression model 2 for boys [%fat = 22.091 -0.147 (height) + 0.760 (∑3SKF) - 0.003 (∑3SKF)^2], and model 6 for girls [%fat = 17.539 + 0.303 (∑2SKF) + 0.516 (height) -0.175 (waist circumference)], which were the most accurate models, and Model 9 [boys:

was %fat = 14.405 + 1.479 (triceps) - 0.856 (age); girls: %fat = 13.936 + 1.170 (triceps) - 0.502 (age)], which was the most convenient model, were selected for further analysis. Repeated *t* tests were computed and the result is shown in Table 11. It revealed that there was no significant difference between $\%fat_{ADP}$ and %fat estimated by Model 2 (t = -1.70, $p > .05$), Model 6 (t = 0.17, p > .05) and Model 9 (t = 1.00 for boys and .99 for girls, $p > .05$).

Table 11
Repeated t-test showing the difference between Model 2, 6 and 9 and $\%fat_{ADP}$.

Model	Gender	Mean	SD	SEM	*r*	*t*	df	*p*
ADP (Criterion)	Boys	19.72	10.62	0.89	-	-	-	-
	Girls	25.81	6.19	.66				
2	Boys	19.20	9.42	0.79	.94	-1.70	141	.09
6	Girls	25.75	5.22	0.56	.84	-0.17	87	.88
9	Boys	19.73	9.56	0.80	.90	0	141	1.00
	Girls	25.82	4.94	0.53	.80	0.02	87	.99

Note. ADP: Air-diaplacement plethysmography; SD: Standard deviation; SEM: Standard error of mean.

Furthermore, to evaluate the accuracy of the models, simple regressions were generated between the estimated %fat and $\%fat_{ADP}$ criterion. It was determined by the slopes and intercepts of the regression lines between %fat estimation and $\%fat_{ADP}$. The results, including β *values* and 95% confidence interval of the slopes and intercepts of the regression lines, are shown in table 12. For both Model 2, 6 and 9, their slopes and intercepts of the regression lines were not different from 1 and 0, respectively, showing that the estimated %fat from these models and $\%fat_{ADP}$ were statistically equivalent.

Table 12

Description of regression Line of Model 2,6 and 9 vs $\%fat_{ADP}$.

	Model		Mean	SE	95%CI Lower	95%CI Upper
Slope		Test value	1.00			
	Model 2	Boys	1.06	0.03	0.99	1.12
	Model 6	Girls	1.00	0.07	0.87	1.14
	Model 9	Boys	1.00	0.04	0.92	1.08
	Model 9	Girls	1.00	0.08	0.84	1.16
Intercept		Test value	0			
	Model 2	Boys	-0.59	0.70	-1.41	0.82
	Model 6	Girls	0.04	1.80	-3.56	3.64
	Model 9	Boys	0	0.90	-1.80	1.76
	Model 9	Girls	-0.01	2.14	-4.33	4.23

Note. SE: standard error; 95%CI: 95% confidence interval.

Figure 5 to Figure 8 are Bland-Altman plots (Bland & Altman, 1986) illustrating how much the estimated %fat were deviated from $\%fat_{ADP}$. In a Bland-Altman plot, the residual (i.e., the difference between the estimated %fat and $\%fat_{ADP}$) are compared to the mean of $\%fat_{ADP}$ criterion and the estimated %fat.

The Bland-Altman plot of Model 2 is displayed in Figure 5, which showing that 87.5% of the residuals fell within 5%. The Bland-Altman plot of Model 6 is displayed in Figure 6, which showing that 85.2 % of the residuals fell within 5%. The Bland-Altman plot of Model 9 is displayed in Figure 7 and 8 for boys and girls, which showing that 76.8% and 78.4% of the residuals fell within 5%, comparing with 66.9% and 78.4% for the Slaughter equations.

Figure 5

Bland-Altman Plot comparing the residuals and the mean of %fat$_{ADP}$ and that estimated from Model 2 [$(\sum 3SKF)^2 + \sum 3SKF$ + Height] for boys.

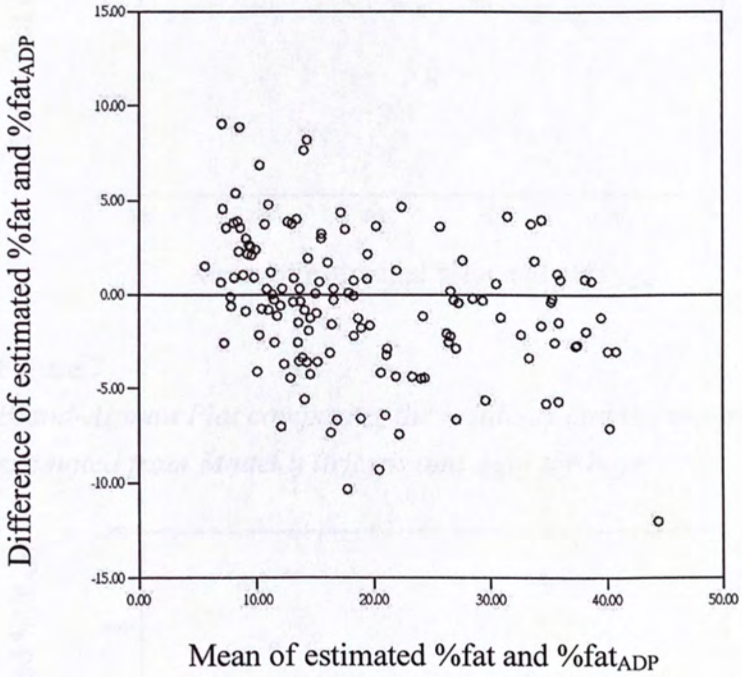


Figure 6

Bland-Altman Plot comparing the residuals and the mean of %fat$_{ADP}$ and that estimated from Model 6 (∑3SKF, height and waist circumference) for girls.

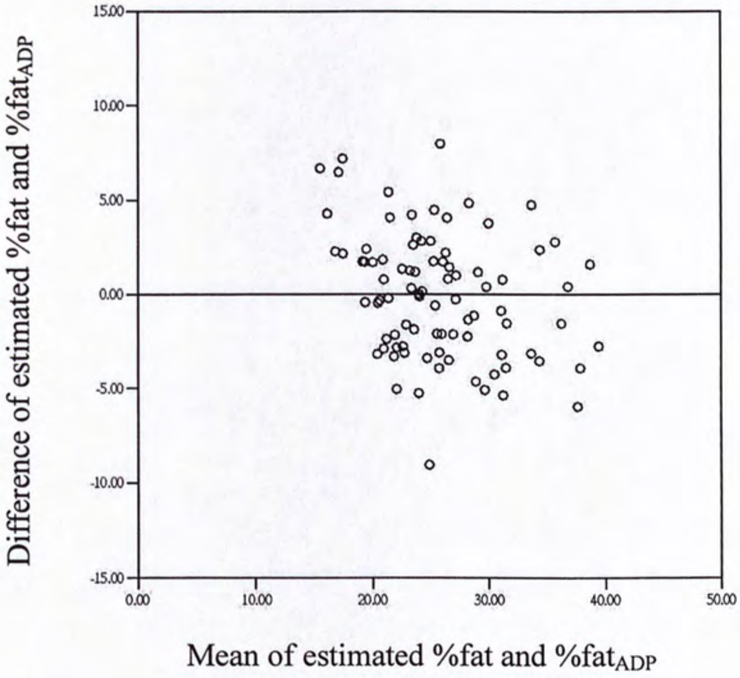


Figure 7

Bland-Altman Plot comparing the residuals and the mean of %fat$_{ADP}$ and that estimated from Model 9 (triceps and Age) for boys.

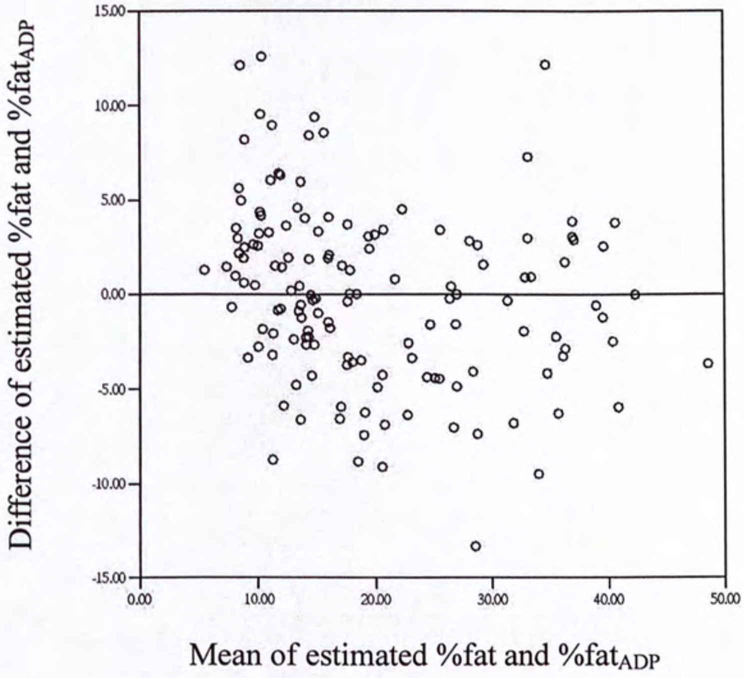
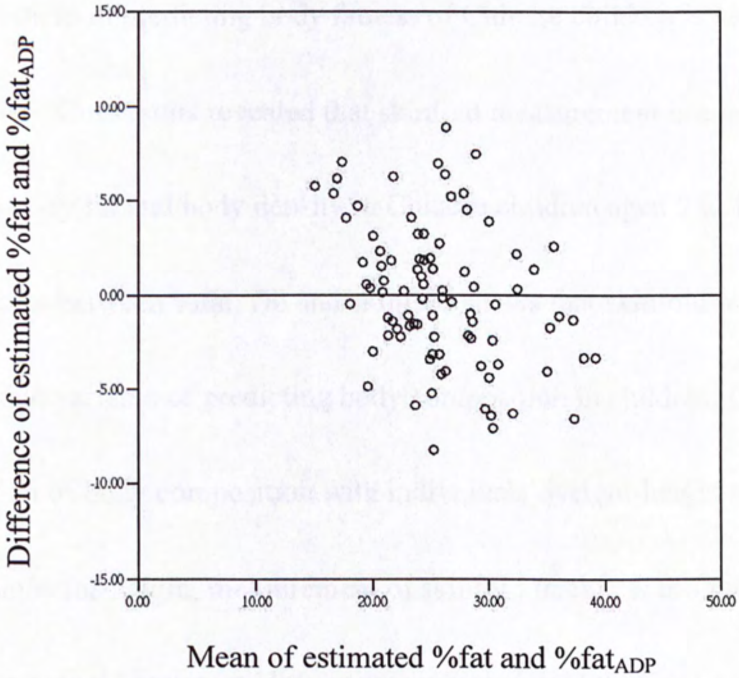


Figure 8

Bland-Altman Plot comparing the residuals and the mean of %fat$_{ADP}$ and that estimated from Model 9 (triceps and Age) for girls.



DISCUSSION

The purpose of this study was to examine the validity and reliability of skinfold measurement in predicting body fatness of Chinese children in Hong Kong using ADP as a criterion. Our results revealed that skinfold measurement is a reasonable estimate of percent body fat and body density in Chinese children aged 9 to 19 years old. The high correlation between %fat, Db and skinfold shows that skinfold measurement is a reasonable variable of predicting body composition in children. Comparing with prediction of body composition with individuals' weight-height relationship, such as BMI and weight-for-height, measurement of skinfold thickness is a measurement of adiposity, which may yield better validity, as researchers found that high adult body fatness is better predicted by adolescent skinfold thickness than by adolescent BMI (Nooyens et al., 2007). However, these two methods are of different purposes. The BMI should be utilized as a screening tool for parents and school setting since its ease of use. The skinfold method should be treated as an alternative of laboratory measurement in clinical setting where laboratory test equipment such as Bod Pod and DXA machine is not available.

Comparison of ADP and DXA in measuring %fat has been made in a sub-sample in our study. The %fat measured from ADP and DXA is not different from each other, which is in line with previous studies (Dewit et al., 2000; Fields & Goran, 2000) that the regression relationship of fat mass by ADP and 4C model did not significantly deviate from the line of identity. ADP is supported as an acceptable way to obtain the criterion measure of body fat for children.

Regarding to the reliability of skinfold measurements, Ferrario and colleagues (Ferrario, Carpenter, & Chambless, 1995) found that triceps skinfolds and subscapular skinfolds had high inter-examiner reliability ($r > 0.91$). Similar result was also found by Mueller and Malina (2005), which the intra- and inter-examiner reliability of skinfold thicknesses at five sites was .937 and .915, respectively. In our study, the internal consistency of skinfold measurement were even higher ($r = .988$ to .996), which supports skinfold as a highly reliable measurement.

A number of studies concerning about the validity of Slaughter equations were conducted in the past. The accuracy of the Slaughter equations varies in different validation studies. A summary of these studies is shown in Table 13. Though some of the studies found that the accuracy of the Slaughter equations were acceptable (Louie et al., 2001; Steinberger, Jacobs Jr, Raatz, Moran, Hong, & Sinaiko, 2006), most of them suggested that there is a need of refinement in order to obtain a more accurate %fat estimation (Goran, Driscoll, Johnson, Nagy, & Hunter, 1996; Hui et al., 2001; Janz et al., 1993). Janz and colleagues (1993) found that the SEE of Slaughter equations ranged from 3.5 to 4.6%, and the prediction was significantly different ($p < .05$) from the criterion measurement. Hui and colleagues (Hui et al., 2001) found that the the Slaughter equations shared small variances with the criterion with large standard error of estimates (SEE) for both boys ($R^2 = .25$, SEE = 8.02%) and girls ($R^2 = .21$, SEE = 6.71%). Reilly and colleagues (Reilly, Wilson, & Durnin, 1995) found that the existing published skinfold equations, including the Slaughter equations, were associated with large random errors or significant systematic errors.

Table 13

List of validation studies of the Slaughter equations on healthy school children

Study	Ethnicity	Gender	Age	N	Criterion	SEE	Comment
Original study (Slaughter et al., 1988)	Caucasian. African-American	Boys & girls	8-17	242	4-C Model	3.8%	
Janz et al. (1993)	Caucasian	Boys & girls	8-17	122 (67B, 55G)	UWW	3.5-4.6%	Hold promise, but refinement needed
Reilly et al. (Reilly et al., 1995)	Caucasian	Boys & girls	5-11	98 (64B, 34G)	UWW	-	Poor agreement (wide limits of agreement from Bland-Altman plots)
Goran et al. (1996)	Caucasian, Native American	Boys & girls	4-10	50	DXA	4.6%	Systematic error exists
Louie et al. (2001)	Chinese	Boys & girls	6-12	44	UWW	3.69%	Acceptable, but underestimated 2.3% fat
Hui et al. (2001)	Chinese	Boys & girls	8-13	141 (66B, 75G)	UWW	Boys: 8.02% Girls: 6.71%	
Steinberger et al. (Steinberger et al., 2006)	Caucasian, African-American	Boys & girls	11-17	130 (72B, 58G)	DXA	Boys: 4.17% Girls: 3.88%	Moderately effective ($r = .69 - .79$)
This study	Chinese	Boys & girls	9-19	230 (142B,88G)	ADP	Boys: 4.67% Girls: 3.77%	

Note. UWW: Underwater weighing; DXA: Dual-energy x-ray absorptiometry; ADP: Air-displacement plethysmography.

The Slaughter equations have established for 20 years, yet no in-depth validation work has been done for Chinese children in Hong Kong. In this study, a total of 230 participants aged from nine to nineteen years old were covered. It was one of the largest scale validation studies of Slaughter equation among Chinese children. The sample size, age and %fat of the sample covered in this study may be more representative than other previous studies (Hui et al., 2001; Louie et al., 2001).

t-test revealed significant difference between $\%fat_{Slaughter}$ and $\%fat_{ADP}$, and the slope of the regression line of Slaughter equation for boys was significantly different from the line of identity. One possible reason accounts for the difference may be the effect of ethnicity. Scientists found that, for the same BMI, the %fat of Chinese was 3–5% higher compared to Caucasians (Deurenberg, Deurenberg-Yap, & Guricci, 2002), thus the prevalence of obesity for Asian is likely underestimated. This discrepancy may be explained by differences in trunk-to-leg-length ratio and differences in slenderness (Deurenberg et al., 2002), and the fact that for a given total body fat, majority (98%) of Chinese participants has a greater proportion of visceral adipose tissue (Lear, Humphries, Kohli, Chockalingam, Frohlich, & Birmingham, 2007). Hence, as suggested by Heyward (2001), a valid skinfold equations should be ethnic-specific, and the Slaughter Equations are recommended for estimating %fat of African American and Caucasian children and adolescents only. The equations should be validated, and modified if necessary, prior to applying in a sample of different ethnic group. Alternative equations or refinement of the Slaughter equations is thus suggested in order to have more accurate estimation on %fat of Hong Kong children.

In this study, a total of nine skinfold regression models were developed, and three of them (Model 2, 6 and 9 in Table 10) were found to be superior than the others. The high R square and low SEE of these three models are comparable to that of the original Slaughter equation, showing that the models are good predictors of %fat for HK children. The Bland-Altman plots of these three models, however, show less deviation than that of the Slaughter equation. The alternative models agree more than the Slaughter equations in predicting body composition of Chinese children in HK.

It is found that triceps skinfold is the best predictor of $\%fat_{ADP}$ This is in line with the study done by Sardinha and colleagues (Sardinha, Going, Teixeira, & Lohman, 1999). They reported that triceps skinfold thickness gave the best results for obesity screening in adolescents, comparing with BMI and arm circumference. A local study done by Hui and colleagues (2001) also found that it is acceptable to adopt triceps as the only predicting variable for boys.

Scientists suggested that there was an interaction between the SKF equation and subject maturation level (Janz et al., 1993; Reilly et al., 1995). The inclusion of age as a variable in the equation may produce better %fat estimation. The skinfold model 9 of our study was in line with this finding, which age is included as a variable to predict %fat. The Model 9 is also regarded as the convenient model, which only measurement of one skinfold site (i.e: triceps), and subject's age, is needed for the %fat estimation. It is more convenient than the Slaughter equations, since measurement of calf skinfold can be omitted while accuracy is unaffected.

Limitations

Two-component model as a measurement method

Due to lengthy procedures and difficulty in performing the tests required for the multicomponent model, including UWW, hydrometry, DXA and ADP, it would be difficult to carry out all the tests in order to obtain body density, total body water and bone mineral mass, especially for children. However, if equipments and resources are available, the most accurate way to carry out body composition research is to adopt the multicomponent model, which is regarded as the gold standard of measuring %fat, as the criterion.

Age Range

In this study, the minimum age of participants was nine, and it is identical to the only previous study published so far in which the 4-C model was used in children to compare with ADP (Fields & Goran, 2000). Nevertheless, until further validation is made, the equations suggested in this study were only valid for HK children aged 9-19 years old.

Recommendations for Future Study

Cross validation

In order to further determine the applicability of the skinfold models proposed in this study, cross validation of the proposed models using different criteria measures, such as DXA, UWW, hydrometry or a combination of these methods (i.e. multicomponent model), should be determined.

Conversion of previous skinfold data to %fat

Skinfold data collected in recent years can be converted to %fat by adopting skinfold models introduced in this study for more accurate estimation of the prevalence of childhood obesity in HK, as previous figures of childhood obesity in HK were generated using crude indices such as BMI or weight-for-height as the criteria. By understanding the figure with %fat, not only the trend will be observed, but scientists and practitioners will be able to know the actual body composition of the children. The effectiveness of health promotion strategies in Hong Kong can then be evaluated more validly.

Conclusions

In summary, this study showed that skinfold measurement is a reasonable estimate of percent body fat and body density in Chinese children aged 9 to 19 years old. The reliability of skinfold measurement was very high. We compared the existing Slaughter equations with that measured by ADP in Chinese school children. Significant difference was found between two estimations, and the slope of the regression line of Slaughter equation for boys was significantly different from the line of identity. We proposed three alternative skinfold prediction models for estimating percent body fat of Chinese children in Hong Kong, which combining anthropometric measurements and children's age. The most accurate model for boys was %fat = 22.091 -0.147 (height) + 0.760 ($\sum$3SKF) - 0.003 $(\sum 3SKF)^2$, and that for girls was %fat = 17.539 + 0.303 ($\sum$2SKF) + 0.516 (height) -0.175 (waist circumference). The third model for boys and girls was the convenient model, as only triceps skinfold and age is required for the estimation. The equation for boys was %fat = 14.405 + 1.479 (triceps) - 0.856 (age), and the equation for girls was %fat = 13.936 + 1.170 (triceps) - 0.502 (age). The accuracy of these models is comparable to the Slaughter equations, but the estimated %fat by these alternative models were less deviated from $\%fat_{ADP}$ than that estimated by the Slaughter equations.

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Appendix A

Standardized Description of Skinfold Sites (American College of Sports Medicine, 2005)

Abdominal	Vertical fold; 2 cm to the right side of the umbilicus
Triceps	Vertical fold; on the posterior midline of the upper arm, halfway between the acromion and olecranon processes, with the arm held freely to the side of the body
Medial Calf	Vertical fold; at the maximum circumference of the calf on the midline of its medial border
Subscapular	Diagonal fold (at a 45° angle); 1 to 2 cm below the inferior angle of the scapula
Suprailiac	Diagonal fold; in line with the natural angle of the iliac crest taken in the anterior axillary line immediately superior to the iliac crest
Thigh	Vertical fold; on the anterior midline of the thigh, midway between the proximal border of the patella and the inguinal crease (hip)

Appendix B

香港中文大學 體育運動科學系
香港學童皮摺厚度驗證測試

參加者同意書

Subject code:____________

Name:____________

為了驗證皮摺厚度測試在量度香港學童脂肪比例的可信性及有效性，本人**同意**義務參加以下測試：

<u>測試簡介</u>

1. 身高，體重，臂圓周及腰圍量度;
2. 脂肪比例（排空氣法）測試;
   受測試者將坐於脂肪比例分析儀 Bod Pod 內，以排空氣法評估身體的脂肪百分比。
3. 皮摺厚度測試:
   量度皮摺厚度作為評估身體成份的指標。量度皮下脂肪的位置為:
   a) 肱三頭肌；b) 肱二頭肌; c) 肩胛下部; d) 髂脊上部; e) 大腿；及 f) 小腿。

<u>危險及不適</u>

這項實驗並沒有已知的風險。但在進行皮摺厚度測試期間，皮膚可能會因被擠夾而產生少許痛楚，但研究員將盡最大能力避免。

<u>測試的預期得益</u>

以上測試是以科學方法準確地評估學童的身體密度及脂肪比例，以分析學童的健康體適能狀況。除非得閣下之同意，本測試結果將絕對保密。

<u>查詢的自由度</u>

研究員歡迎受測試者隨時發出任何有關測試之提問，若有任何困惑、疑問，或需要知道更多資料，請自由提出。

<u>同意參與的自由度</u>

閣下同意參與測試與否，有絕對的自由權。受測試者於任何時候都可自由停止測試。 如對是項研究有任何疑問，請致電:

香港中文大學體育運動科學系　楊智誠先生: 2609 8069　　許世全教授: 26096081

本人已詳閱此同意書及明白以上的測試過程。本人同意參加以上測試。

參加者簽署：____________　　見證人簽署：____________

日期：____________　　日期：____________

參加者監護人簽署：____________　　研究員簽署：____________

日期：____________　　日期：____________

Consent for Participation in Research Form

1. **Purpose.** The purpose of this study is to examine the validity and reliability of skinfold measurement in predicting body density and percent body fat of Chinese children in Hong Kong aged 6 to 19 years old, using Air Displacement Plethysmography (ADP) as criterion.
2. **Test Protocols.** Body density and body volume will be measured by the Bod Pod. Body height, body weight, waist circumference and skinfold of different body sites, including triceps, subscapular, supreiliac, abdomen, thigh, and calf, will be measured by a skinfold caliper.
3. **Risks and Discomforts.** There is no known risk in these tests. Extensive efforts are made to minimize discomfort during skinfold measurement. Trained personnel and emergency equipment are immediately available to deal with any unusual occurrences.
4. **Participant Responsibilities.** It is imperative that I promptly report any health related symptoms if they occur during the test.
5. **Expected Benefits.** The results of the test may be useful in determining my current level of body composition. I will find out where I am physically compared to national standards.
6. **Inquiries.** Any question, concerns and comments regarding procedures or use of results are encouraged. I can ask for any further clarification and explanation if needed.
7. **Use of Results.** The information obtained from the test will be treated with confidentiality. Results may be use for statistical analysis or scientific purposes with your right to privacy retained.
8. **Freedom of Consent.** I hereby consent to voluntarily engage in exercise testing to determine my exercise capacity and state of cardiovascular health. My permission to perform this exercise test is given voluntarily. I understand that I am free to stop the test at any point, if I so desire.

I have read this form, and I understand the test procedures that the participant will perform and the attendant risks and discomforts. Knowing these risks and discomforts, and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this test.

______________	________________________
Date	Signature of Participant
______________	________________________
Date	Signature of Parents
______________	________________________
Date	Signature of Witness

Appendix C

Children Body Composition Lab

Subject Code: ___________ **Date:** __________ **Height:** ________.___cm

Name: ___________ **Date of Birth:** ___(D)/ ___(M)/ ___(Y) **Age:** ___ **Gender:**

___

Waist circumference: __________ cm Arm circumference: ___________ cm

Skinfolds (mm)	1st Trial	2nd Trial	3rd Trial
Triceps			
Biceps			
Subscapular			
Suprailiac (Hip)			
Thigh			
Calf			

ADP	1st Trial	2nd Trial
Body volume (l)	/ / =	/ / =
% fat (%)		
Body weight (kg)		
Fat weight (kg)		
Lean weight (kg)		
Lung volume (L-P)		
Body density (kg/l)		